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AMBIENT TOXICITY TO ASSESS BIOLOGICAL IMPACT

by

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16. ABSTRACT

The frequent occurrence of xenobiotic chemicals in surface water is of concern to regulatory agencies and the public. The impact of these must be distinguished from impacts due to other factors such as low oxygen, habitat or dredging before an understanding of expected improvement from their reduction can be achieved.

An ambient toxicity test is described, which is competitive in cost to G.C. analyses, that can be used to discuss if the chemicals present are causing toxicity. In field studies completed recently, the correlation between toxicity measured in ambient tests and the impact on biological communities was highly significant.

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I. INTRODUCTION

Two of the most important reasons for water pollution control programs are to protect human health and to protect biological communities. While the human health concern might be considered the more important, there is not a direct connection between water quality and health effects because of the removal of contaminants during drinking water treatment and the limited exposure to surface water. Many of the past health concerns have been because of bioaccumulation. Concern about protection of biological communities has probably received as much or more attention than health concerns, perhaps because there is a more obvious connection between water quality and effects on aquatic organisms.

For decades, biologists have measured characteristics of aquatic communities to assess their well-being. Much of the effort has been an attempt to find "the all-encompassing measure" that will define the damage and point out the cause. With today's emphasis on chemical contaminants and knowledge of the large number of them that are to be found in surface water, it is easy to blame "toxics" for all undesirable impacts found and it is easy to assume that the next discharge upstream is the source. The presence of chemicals in a water body does not mean they are having adverse impacts. The impact on biological systems from toxic chemicals is a function of time and concentration. Rarely do our monitoring measurements tell us much about the duration of the measured concentrations.

Perhaps we need to examine the generic types of factors that influence the health of aquatic communities first, and then decide if the chemicals present are causing a toxic effect. A first step we need to take may be to determine whether toxicity exists before deciding that the chemicals present are causing the impact observed. Biological cycles, over-fishing, weather, flow-alteration, habitat changes, temperatures, excessive nutrients, dissolved oxygen, disease, predator-prey relationships, energy flow changes and many other causes may be equally or

more important than toxic chemicals in causing changes. As difficult as analytical measurements may be, they are often easier than measuring the biological effect of these other factors and perhaps we are jumping to conclusions because chemicals are present. I suggest we first identify if toxicity is present, not just assume toxicity occurs because chemicals are present. It is certain that providing upgraded waste treatment plants to remove chemicals will not help if the problem is caused by weather or nutrients.

Aquatic communities are too complex and too poorly understood to study directly to discern if toxicity is causing the impairment, with any practical amount of effort. Furthermore, many of the needed answers have to be made available before substances are to be released into the environment or before environmental alterations occur. Usually such answers must come from laboratory tests.

2. A TOOL

2.1 Type of Test Needed

Fortunately, detecting toxicity is probably easier and quicker than detecting effects of other stresses mentioned above. Toxicity can be measured following many of the same principles used to measure chemicals, by conventional analytical procedures. Toxicity should be viewed as a potential characteristic of water and as such can be measured by sampling and laboratory analyses. This is not true of over-fishing, climatic changes, or habitat changes. Toxicity then should be one of the first factors measured when attempting to identify the cause of community impairment.

Most surface water samples do not show acute toxicity, so in order to determine if toxicity occurs in water samples, chronic toxicity must be measured. Until recently, available chronic tests on aquatic species have been months to years in length. Such tests are too expensive to use for purposes discussed here both because of the length of time required and the volume of sample needed. For

this type of monitoring (hereafter called ambient testing) one needs to measure toxicity on samples from various sampling sites which may be far separated geographically. Obviously then, samples must be shipped to a central point for testing which makes conventional flow-thru testing impractical.

Fortunately, some new tests have been developed that allow chronic toxicity to be measured in one week (Mount and Norberg[2] and Norberg and Mount [11]). Any test that measures chronic toxicity can be used; the advantage of these tests is that they take the shortest time to run and require the least volume of sample (Dr. Steve Schimmel of EPA, Narragansett, R.I. is completing similar tests for marine organisms). The particular species used have no other unusual inherent qualities and certainly the fathead minnow growth test method (Norberg and Mount[11]), could be modified to use other species of larval fish. Daphnia magna chronic tests (Mount and Norbert[2]), used so widely for toxicity testing, should also be amenable to scaling down volumes and shortening the test period.

The specific details of animal culture, handling, replicates and data analyses can be found in the published papers. For purposes here the samples to be tested, using the published methods, need to be discussed.

In usual toxicity tests, various dilutions of the sample are made to determine the threshold effect concentration. Rarely are ambient samples of surface water toxic enough to require dilution. Therefore, samples from designated locations are tested for toxicity as they are received after temperature adjustment. (Note: Temperature adjustment which can change toxicants is necessary since only at appropriate temperatures will adequate reproduction and growth occur. McNaught and Mount[1] found that Ceriodaphnia can be tested over a wide temperature range but at cooler temperatures much longer test periods are needed). Each sample can be viewed as a separate toxicant or treatment and by comparing the

response in samples from various stations, a relative toxicity value can be obtained for each station.

2.2 Station Selection and Sampling

Selection of stations is a site-specific decision depending on geography and hydrology and the degree of resolution desired. In flowing streams a series of upstream-downstream stations are usually selected after giving proper consideration to discharges, tributaries, reservoirs and especially important niches or segments. If long reaches (e.g., 100 miles) are to be sampled, a "screening" phase in which a station every ten miles and/or a station below each major tributary may need to be done first to locate where the most toxic conditions occur. This phase can be followed by a more intensive one in which the segments found to be toxic are sampled throughout relative to potential inputs to pinpoint more exactly sources of toxicity.

The eight site-studies referenced in Section 3 reveal some cautions about sample station location. Never assume that headwater stations will be non-toxic because often they will contain old mines, dumpsites, springs contributing contaminated groundwater, pesticides, or naturally occurring toxicants such as heavy metals. Even if some sought-after species such as rainbow trout are found, toxicity may exist but not of sufficient strength to obliterate the trout population. Secondly, when a tributary or a discharge enters, even if toxic, the toxicity of both may disappear in the mixture. "Antagonism" has occurred frequently during these studies. For lake or reservoir situations, sampling stations can be located in reference to tributaries, harbors, discharges and stratification. In water subject to tides or currents, these factors must be considered.

Once the stations are chosen, sampling protocols are important. Contaminants are not usually present continuously or at constant concentrations. If this is so, then a grab sample may give a totally different test result than a

composite sample. While a grab sample has the potential to show maximum toxicity it also has maximum chances of missing maximum toxicity completely. A composite sample is a compromise for both concerns.

Composite samples may be difficult to collect. Since the tests are renewal tests, or can be, a good plan is to obtain a new sample on each of the seven days and expose the test organisms to it for 24 hours. In this way, the exposure occurring at the station is best simulated in the toxicity test. Especially for tidal locations, the use of daily composite samples provides the best practical exposure simulation.

The results of the tests can be affected drastically by rainfall or flow changes due to flow-regulation. If discharges from treatment plants, seepage or springs are of concern, the concentration of these in the receiving water will be greatest at low-flow conditions. On the other hand, insecticides and other runoff related contaminants may be at the highest concentration during high flows. The hydrologic conditions for proper sampling time must be selected based on such considerations. The test results will be no better than the representativeness of the samples tested. For variable conditions, sampling may have more bearing on the results than choice of test species or test type and may well be the most expensive of all. But expense of sampling is well justified in the validity of the results.

2.3 Methods Considerations

Finding a good control for ambient samples is difficult. There are not yet foods or standardized test waters which can be specified that will mimic test organism response in a given natural water. Such characteristics as nutrient content, suspended solids and other unknown factors will change the organism performance. Therefore, the best approach now available is to use as a quality

assurance requirement, a treatment in which a good quality water is used and for which organism performance is known. This will reveal if the lot of test organisms was of good quality and test conditions were acceptable. These data should not be used for statistical comparison for data analyses, however, for reasons described above.

Since there is no predetermined way to know which ambient samples are not contaminated, the station sample in which the organisms performance is best is used for statistical comparison. Thus, the results give a relative toxicity value rather than an absolute one. If the organisms' performance at all stations is very low, e.g., five young/female and the QA treatment gave twenty, one should assume that all samples have toxicity. However, if one or more stations had 15 young, such numbers may not be statistically different from the QA sample and therefore, may not display toxicity. In such cases, judgment must be used. The concern is that if only relative toxicity is used, one may get relative differences among the stations but none will be without toxicity and so no station would be considered acceptable.

Ambient tests can be used to determine if toxicity is a contributing cause to community impairment and should be viewed as an analytical measurement, only in this case the "detector" is an organism rather than an electronic "black box." Like every analytical measurement, the "detector" has a limit of sensitivity. The limit can be lowered by using more species for testing. The test will measure every substance but the detection level will vary greatly depending on the substance. Ironically, the sensitivity is greatest to those substances most toxic. And those are the ones we most want to identify.

3. AN EXAMPLE

A series of eight reports (Mount et al. 1984[8], 1985[4,7], 1986[3,5,6,8], and Norberg-King and Mount, 1986[10]) have described a large scale effort to

determine if such tests on ambient water samples correlate with the species richness of the sampling stations from which the tested water was taken. Eight sites were evaluated. An example of a correlation found is shown in Figure 1. The data are from the Kanawha River in West Virginia (Mount and Norberg-King, 1986[3]). Nearly 100 miles of river were sampled for zooplankton and macroinvertebrate species richness. This river historically has been one of the more seriously polluted rivers in the U.S., mostly from a heavy concentration of chemical industry. The study reach was all within three navigation pools and since there are no major tributaries, the effect of habitat over the study reach was lessened. The toxic effects as measured by the toxicity tests and the changes in species richness of zooplankton were not large, yet a correlation analysis was significant at a P of $< .001$. The macroinvertebrates were sampled using artificial substrates and they showed a decreasing species richness from upstream to downstream. There was no correlation between the toxicity results and the macroinvertebrates.

These results illustrate several important observations that can be drawn from the eight site studies in general and in conjunction with what is known about the sensitivity of various aquatic species. (The reader is referred to Blanck, 1984[12] for a more thorough review of the matter of inferring community impact using single species tests.) From the toxicity data base now in the literature, differences in the sensitivity of organism within a major group, e.g., aquatic insects, are frequently three or four orders of magnitude. Differences in the sensitivity of a given organism to a variety of chemicals is known to span seven orders of magnitude (Blanck 1984[12]). Suter II et al. 1985[13] showed that the more different the species are taxonomically, the greater the differences in sensitivity. These toxicity data then imply that within a community we should expect various groups (benthos, zooplankton, fishes, phytoplankton) to respond

quite differently to a toxic chemical or mixture of chemicals. The implication one gets when reading many biological survey reports on contaminated reaches is that all groups of the community should decline and recover in harmony. If not, why would so many surveys examine only benthos or fishes? However, the toxicity data base clearly indicates that we should expect various groups to respond differently. The eight site studies also clearly show that to be true. Finally, if various groups do respond differently, then obviously toxicity data from a single species cannot correlate with all groups of organisms in the community. The more severe the impact, the better and the more correlations there should be.

Thus, the Kanawha data fit the expected. The benthos and zooplankton responded differently and so naturally the toxicity data could correlate with only one aquatic group. Also, the species richness was high enough to infer that the impacts are not massive.

4. TOXICITY PROFILE

If sampling stations are located over a reach of stream or segment of a lake and the toxicity measured in samples from those locations, a toxicity profile can be constructed from the data. The profile will show where toxicity occurs and where it is absent. One such profile is shown in Figure 2 (Mount et al. 1984[9]) in which the reproductive rate of Ceriodaphnia is shown on the vertical scale and river stations are shown from upstream to downstream over approximately 27 miles of stream, on the horizontal scale. Increased toxicity occurs below Station 2 as shown by the reduced number of young produced. Two discharges were located downstream of Stations 2 and 3. These effluents had chronically unsafe concentrations less than the waste concentrations occurring at those stations (Mount et al. 1984[9]). Through fate processes causing decay of effluent components, and by dilution, the toxicity decreases at down-stream Stations 7 to 9 where reproduction is as good or better than at Stations 2 and 3. The greater

young production is attributed to enrichment by nutrients from agricultural runoff and domestic wastewater from small downstream plants.

A different type of plot would be needed for a lake situation where there is not a clear upstream-downstream relationship as in a river. Isopleths of toxicity could be used, for example, to describe data from a lake or harbor to give a comparable profile.

The eight site studies have shown that such profiles are predictive of community impact. As discussed above, the profiles did not, nor were they expected to predict the impact for all community groups. More predictions could be made by gathering toxicity data on more species. The paper by DiToro, Holden, and Plafkin, contained in this volume, illustrates how such data can be used in modeling toxicity as well.

5. SUMMARY

The use of toxicity tests is a cost-effective tool to use in conducting biological community assessments, especially where the cause of impact is to be identified. The ambient toxicity test is especially good for this purpose and in these eight site studies it revealed many unsuspected sources of toxicity. If toxicity is not the cause of impact or if the wrong effluents are suspected of being the toxicity source, no expenditure for waste treatment plants to remove contaminants will alleviate the impact. Presence of chemicals does not mean adverse impact, but presence of toxicity does. Only organism responses can measure toxicity.

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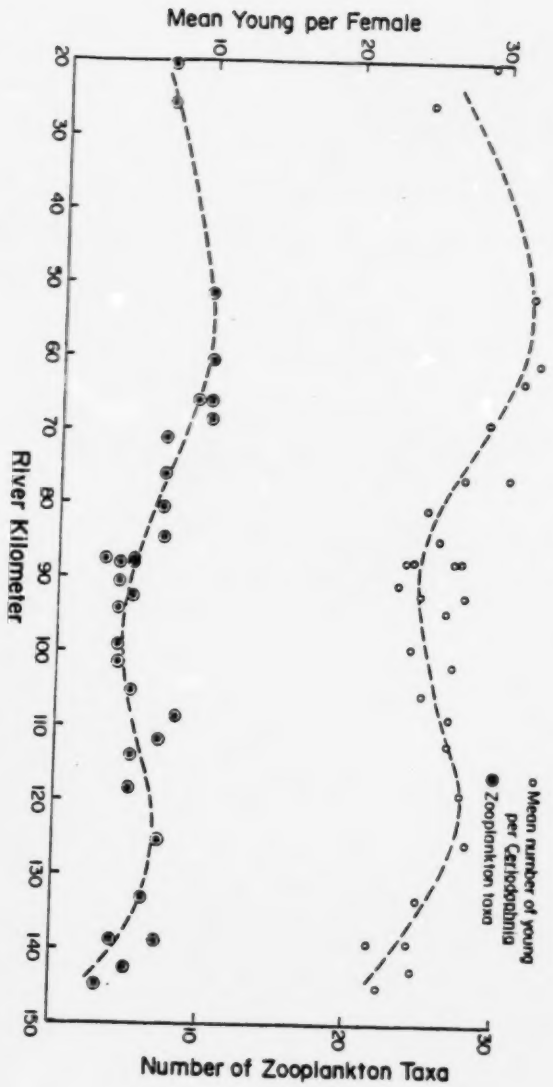

Figure 1. Young Per Female and Zooplankton Species Richness at Ambient Stations on the Kanawha River (from Mount and Norberg-King, 1986).

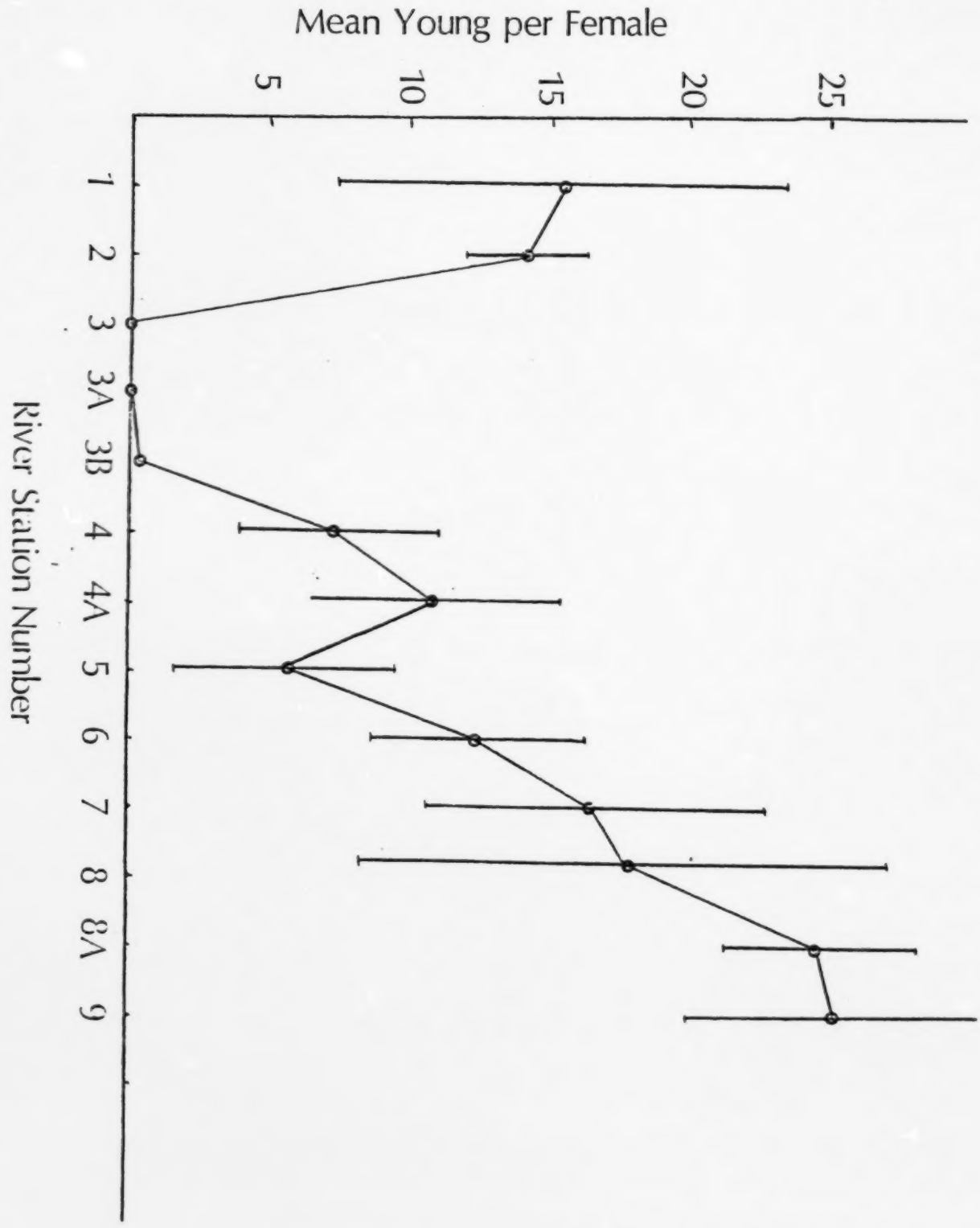

Figure 2. Ambient Toxicity Profile at Thirteen Ambient Stations on the Ottawa River. Vertical Bars are Standard Deviations (redrawn from Mount et al., 1984).